南半球成層圏極域の物質輸送における擾乱の役割について

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On the role of disturbances in the mass transport in the stratospheric polar region of Southern Hemisphere

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The stratospheric material circulation (called "Brewer-Dobson circulation") is examined by a lot of studies using the residual-mean meridional circulation on the Transformed Eulerian Mean (TEM) equations. However, the TEM equations express zonal-mean fields and do not provide a three-dimensional view of transport. Several previous studies extended the TEM equation system to three dimensions but usually under the quasi-geostrophic assumption, which is not satisfied for small-scale phenomena such as gravity waves. Recently, Miyahara [2006], Kinoshita et al. [2010], and Noda [2010] derived a three-dimensional (3-D) wave activity flux and residual-mean flows applicable to gravity waves on the transformed time mean (hereafter called "TTM") equations. Although the 3-D residual-mean flows are regarded as a natural extension to three dimensions of the residual-mean meridional circulation in theory, the time-mean gradient (or geostrophic) flows are included in the 3-D residual-mean flows while the zonal-mean gradient (or geostrophic) flows are vanished on TEM equations. Thus, it is needed to examine the 3-D residual-mean flows caused by disturbances that gradient flows are eliminated from the 3-D residual-mean flows.

The present study calculated the 3-D residual-mean flows caused by disturbances and examined the three-dimensional structures of the horizontal mass transport in the stratospheric polar region of Southern Hemisphere using ERA-Interim reanalysis data. As a result, it is found that the zonal component of 3-D residual-mean flow is eastward /westward in the region of the inside/outside from the center of polar night jet and the meridional component of 3-D residual-mean flows is outward/inward from the polar night jet in the Eastern/Western Hemisphere above 20 hPa in September and from 30 to 3 hPa in October. It is also confirmed that the term of the horizontal component of 3-D residual-mean flows caused by disturbances is balanced with the term of 3-D wave activity flux divergence in the TTM horizontal momentum equation. The disturbances having small zonal wavenumber "s" are dominant in the stratospheric polar region in the winter hemisphere. As a result of decomposing disturbances by their zonal wavenumbers, it is found that the structure of the zonal and meridional components of 3-D residual-mean flows are mainly determined by the momentum flux divergences caused by disturbances having zonal wavenumber 2 and the disturbances having wave number 1 and 2, respectively:

$$f\overline{u^*} \approx -\frac{\partial \overline{v'^{2}_{(s=2)}}}{\partial y},$$

$$f\overline{v^*} \approx \frac{\partial}{\partial y}\left(\overline{u'_{(s=1)}v'_{(s=2)}} + \overline{u'_{(s=2)}v'_{(s=1)}}\right) + \rho_0^{-1} f \frac{\partial}{\partial z}\frac{\rho_0}{\overline{\theta}_z}\left(\overline{v'_{(s=1)}\theta'_{(s=2)}} + \overline{v'_{(s=2)}\theta'_{(s=1)}}\right),$$

where $\overline{u^*}$ and $\overline{v^*}$ are zonal and meridional components of 3-D residual-mean flows cased by disturbances, f is the Coriolis parameter, $\rho_0(z)$ is basic density, θ is potential temperature, s is the zonal wavenumber. The time mean is expressed as ($\overline{\ }$) and the deviation from it is expressed as ($'$).

Moreover, we will show some results of analysis about stratospheric ozone transport using the 3-D residual-mean flows and 3-D satellite observation data.

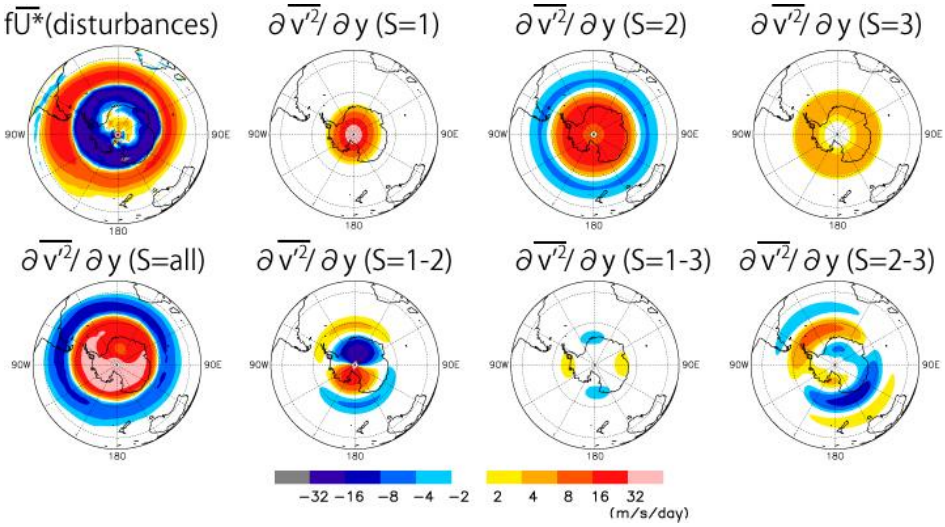

Figure 1. Polar-stereo maps of (left and top) the zonal component of 3-D residual-mean flows caused by disturbances, which are multiplied by *f*, and meridional gradient of the meridional flux of meridional momentum having zonal wavenumber 1-3 (others) at 20 hPa in Southern Hemisphere on October. The zonal wavenumber is expressed as s.

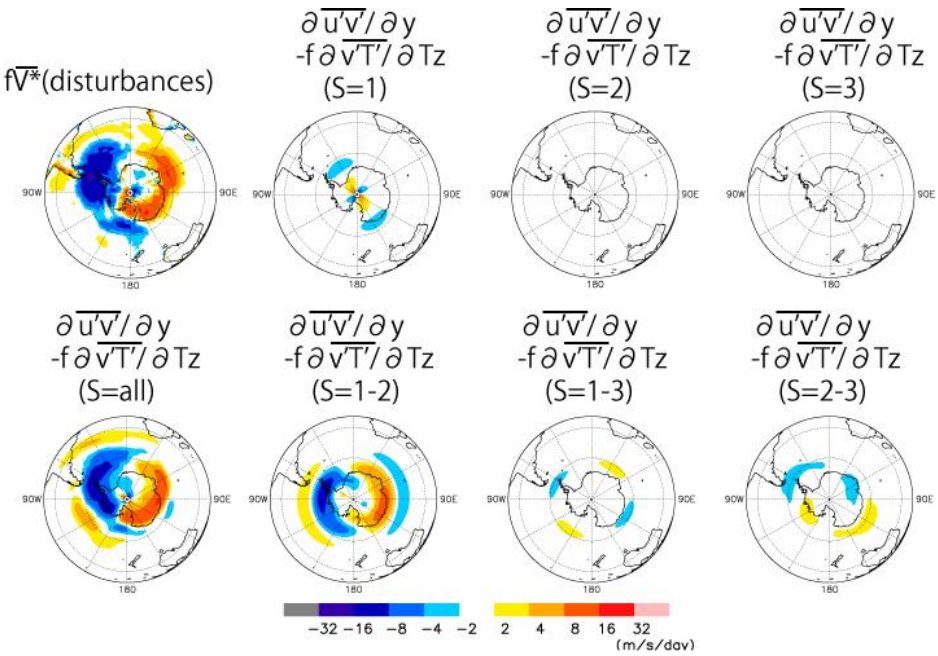

Figure 2. Polar-stereo maps of (left and top) the meridional component of 3-D residual-mean flows caused by disturbances, which are multiplied by *f*, and the sum of meridional gradient of the meridional flux of zonal momentum and vertical gradient of the heat flux of zonal momentum having the zonal wavenumber 1-3 (others) at 20 hPa in Southern Hemisphere on October.
The zonal wavenumber is expressed as s.

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